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ANTIREALISM VS. REALISM IN QUANTUM THEORY

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Scientific realism in quantum physics also aims to make qualified statements about the empirical world, i.e. statements that are logically and empirically coherent. According to Schweitzer, there are three types of theory in particular that can be considered realistic today. The first is the De-Broglie-Bohm theory, which extends Schrödinger's wave function with further dynamic equations and also allows for point particles. The second is the collapse theory, according to which spontaneous discontinuities enter the wave function, each of which leads to discrete results. The third is Hugh Everett's theory, which supplements the second theory with the idea of psycho-physical parallelism, i.e. each measured variant is considered an independent world of perception.[1] (Schweitzer 2022: 156) Schrödinger's wave

function now applies to the whole world, insofar as the possibilities spanned by the function are to be understood as manifest realities. Schrödinger's equation allows excitation states of the connection between atomic nucleus and electron to be calculated exactly *a priori* , whereby only certain states are possible in accordance with quantization.

It can be assumed that there is a universal being that contains the sum of all parallel worlds that can be calculated with the wave function. The sum of all worlds results in 100% of all masses and energies of the universe, insofar as the weighting of the individual worlds decreases with each additional world. Every measurement on quantum objects leads to the necessary splitting into further parallel worlds, whereby no observer, no causality or backward-running times have to be assumed. Chance and contingency are denounced as subjectivist illusions. While the Schrödinger equation describes a plethora of possibilities that are determined, in collapse a single one of these possibilities is declared to be factual, while all other possibilities are regarded as non-factual. In the many-worlds theory, possibility creates a new universe of its own. Each possibility becomes a fact in its own universe. As a result of a measuring process, all possibilities now become facts. This avoids the abrupt change in the Schrödinger equation that can be derived from the Copenhagen interpretation. However, since we only see one pointer position in our world as a measurement result, the other facts cannot occur in our world. The apparent solution is to postulate a new world for each of the possibilities. Since not only the "worlds", but of course also the observers in them are multiplied, "each copy of the observer" sees "its respective fact" in its respective world. (Görnitz) Thus, not only the worlds, but also the observers in them must be multiplied, and so each observer sees his respective factum in his respective world.

These types of theory must at least prove an inconsistency with three assumptions of classical quantum theory, which are that a) the wave function is complete, b) that it develops linearly in time and c) that measurements in a quantum system always only realize a single defined state. A realistic theory must not fulfill all three of these conditions at the same time. For example, the De Broglie-Bohm theory denies the first assumption. The collapse theory denies the second assumption and allows the wave function to collapse spontaneously, not just on the occasion of a measurement. The Everett theory denies the third assumption – in this theory, all possible quantum states can be realized simultaneously, but in multiple worlds. (Ibid.)

For the realistic theories, the Copenhagen interpretation must be considered unrealistic. As already explained, for Bohr the quantum formalism has a heuristic function and only the measurement process and not the state of the system has an ontological dimension. Depending on the theoretical perspective, one will arrive at different interpretations of the measurement results. Either they will be seen as different manifestations of an objective reality, as the realist perspective does, or as the epistemic diversity of the observers, which is incorporated into the measurement concepts. (Heisenberg/Schrödinger).

Arkady Plotnitsky develops his own position on this question with his theory of reality without realism. (Plotnitsky 2021) Plotnitsky understands reality as that which is assumed to exist without being able to make definitive statements regarding the structure of reality. The

absence of such definitive assertions, which is precisely what constitutes realism, makes it possible to locate reality beyond representation. Reality insists on the ability to have effects on the world with which we interact. Quantum events, in turn, are observed as phenomena that can only be defined in the context of measuring instruments or their equivalents in nature. Quantum theory does not provide an image of reality, although this can be confirmed by a variety of experiments. Establishing observable effects of physical reality requires a representation of effects, but not necessarily a representation of how they come about, which may not be possible. The assumption that reality is beyond thought allows us to assume an immeasurably and unimaginably rich reality. This is in line with Baudrillard's assertion that the world has already answered, without any cutbacks, that nothing more can be demanded of it. This means that the reality of the world must be recognized as a surplus, but a surplus that cannot be verified without question, because there is no evidence for the existence of this reality – and there never will be.[2]

It follows from this definition of reality that a theory can assume different levels and different kinds of idealizations of reality, some allowing explication and representation and others not. According to Plotnitsky, the current interpretation of quantum phenomena is based on three fundamental idealizations: 1) The behaviour of the observable parts of measuring instruments, which leads to the definition of quantum phenomena, is idealized as representable. 2) The reality that is ultimately responsible for these phenomena is idealized as that which cannot be represented. 3) The third idealization, which layers the second, is that of quantum objects. On the one hand, in quantum physics, unlike in classical physics or relativity, one must always distinguish in any experimental set-up between the parts of the physical system that are to be treated as measuring instruments and those that form the objects to be investigated. On the other hand, these two parts themselves are not clearly defined, which is sometimes expressed as the arbitrariness of the cut. So it is the way we set up an experiment that defines what the quantum object in that experiment is, while its quantum nature is defined by the ultimate reality whose existence is independent of any experiment. This view applies to all quantum objects, from elementary particles to macroscopic quantum objects. Even macroscopic quantum objects can only be proven to be quantum objects by observations in measuring instruments.

Realistic or ontological thinking in physics manifests itself in theories that generally have a representative character. Such theories aim to at least approximate the reality they consider, usually through mathematized models based on an appropriate idealization of this reality. In quantum theory, it is also necessary to strive for a strictly mathematical representation of reality. However, it is also conceivable to presuppose an independent structure of the reality under consideration without assuming that it is possible to adequately represent this structure by means of a physical theory.

For Plotnitsky, exact predictions (predictions with probability 1) that can be made for certain quantum phenomena are always only predictions about possible events. Predictions do not imply that the theory that makes them possible can represent the ultimate nature of the physical reality that is responsible for possible events. What remains crucial is that predictions presuppose particular circumstances. For Plotnitsky, relationships between quantum

phenomena or events are irreducibly probabilistic.

Like Barad or Plotnitsky, Schweitzer assumes that neither Heisenberg with his matrix formalism nor Schrödinger with his equation make ontological or realistic statements. Both develop mathematical models and not ontological assertions. With Heisenberg, the operators evolve while the states are fixed, which means that no statement is made about the possible values of a state over all times. With Schrödinger, the operator is fixed and the state evolves, which means that the possible states of a quantum system are modeled linearly in time.[3] Bohr, on the other hand, ties any approximate ontological statements to the interaction of object and measuring device. Only Born makes predictions about real states. With him, an ontological component comes into play, namely that of the reality of the quantum object. Schrödinger, on the other hand, considers the wave function itself to be realistic. The wave function is associated with future expectations that correspond to the possible states of the function. However, there is a limited number of options that can be taken. A measurement constitutes a certain catalog of expectations. This catalog, which contains definite and indefinite elements, corresponds to the wave function.[4] From measurement to measurement or observation to observation, new wave functions successively emerge. With each new wave function, there is not only a gain of information, but information is also lost. Deletions indicate that previously correct statements may now be incorrect. There are now wave functions with corresponding catalogs for both the measurement object and the measurement instrument. The intra-actions of measurements intertwine the two systems and a new catalog of future expectations can be created for the overall system. Since the intra-action relationships between the systems must now be taken into account, this results in a large number of degrees of freedom, which, however, contradicts the statement that degrees of freedom are limited due to the quantum-theoretical formalism. Therefore, information and relationship options are not only created by the entanglement, but also destroyed again. A new system is therefore not the sum of its parts, but fundamentally different from the previous system. Beyond recursions, mirroring and self-relationships – think of Baudrillard's fractals – a system-within-a-system paradox (Vogd 2014: 108) can be reported here that implies an interweaving of indeterminacy, a virtuality that makes actualization qua measurement possible. Precisely because of the limited degrees of freedom of systems, entanglement necessarily leads to contingencies, which is the condition for systems to appear in the form of separate units at all. Disentanglements and reconstructions of entanglements occur in a non-trivial time that knows neither continuity nor leap, but only change or fuzzy becoming. The Schrödinger equation would actually be a universal formula in which a sudden collapse of the wave function does not occur. The interfering observer or Bohr's measurement would be liquidated.

In contrast to Bohr in particular, Richard Healey sees quantum formalism as a model for regular statistical patterns that have reality even without measuring agents. Healey sees the performance of a theoretical model primarily in its practicability. At the same time, however, he criticizes realist theories because they assume an ontological status for quantum formalism by overemphasizing the wave function. (ibid.: 158) The ontology of quantum field theory remains controversial, particularly with regard to the creation and destruction of elementary particles in a vacuum. The potentiality of the vacuum is at the center of considerations about embedding quantum field theory in overarching contexts.

At the micro level of quantum field theory, the fundamentality of space is increasingly being called into question by the latest models of theoretical physics. In Rovelli's view, space itself is a product of quantum fields that flow and loop below the level of empirical observation (i.e. at the Planck level). Quantum gravity theory shows that it is mathematically possible and experimentally demonstrable that space itself can be understood as a product of the primary process of folding and bubble formation of quantum fields. This theory is called the "spin foam" theory of space because the currents of quantum fields fold into tiny bubbles, which in turn form larger foam structures; these indicate the seemingly smooth, but actually folded and bubbly topology of space. Thus, the quantum fields are in a state of non-determinacy, while the measurement interacts with the field and indicates a determination in the non-determinate field. Before the measurement, there is no objective discrete stage, but only a non-determinate, continuous flux. The quantum indeterminacy of matter is kinetically real, but not fully empirically actual or visible.
Nail suggests developing a generative or performative materialist explanation of spacetime and black holes. But even an omniscient being with infinite knowledge would not be able to quantify matter exhaustively because it is inherently indeterminate, generative and relational. The belief that matter could ever be described as a closed or bounded system with a limited range of possibilities that obeys invariant laws therefore seems to be an illusion.

Thomas Nail believes that black holes could form the historical basis for a new theory of materialism in which matter is no longer passive, negative or even probabilistic. This new performative materialism is characterized by three core features (Nail 2022):

1) If virtual black holes index the primordial creativity of all matter, spacetime, and quantum fluctuations, then for Nail all matter, from the Planck scale to the macro level, must be defined by a "pedetic" materialism. This means that the laws of nature, including the Planck limit and probabilities, are products of a primarily indeterminate process that iteratively changes and revises over time.

2) Matter is not a continuous or discrete substance moving in spacetime, rather it creates spacetime. Black holes are neither passive matter nor empty voids. Considering what is known about black holes without ignoring the measurement problem and indeterminacy, this points to an interpretation in which matter is an endlessly vibrating, fluctuating and creative process that is more fundamental than spacetime or the Planck scale. The black hole is not characterized by an infinitely small singularity, as predicted by general relativity, but merely by indeterminate moving energy[5].

3) The indeterminacy of a black hole points to an interpretation in which matter manifests itself relationally and immanently. Matter is not a passive or random object, but is formative, creative and creative. However, one could also argue with Görnitz or Simondon that the initial nucleus is not a form or matter, but a structural constitutive potential, i.e. that it carries a kind of *information* that determines the basic conditions for an event to occur.

[1] While the Schrödinger equation describes an abundance of possibilities, in collapse only a single possibility is actualized as a fact, while all other possibilities are regarded as non-factual.

[2] See also Kostas Axelos: The world that is seen as existing only through thinking – as a problem – or that is thought to exist independently of thinking, these two positions fall under thinking and are carried by the world. (Axelos 2023)

[3] One year later, Heisenberg's matrix mechanics was supplemented by Schrödinger's "wave mechanics". The "Schrödinger wave equation" is a partial differential equation. It uses the differential calculus invented by Leibniz to relate changes in continuous physical quantities to external conditions. The handling of such mathematical structures, which is equivalent to a deductive method, has long been used in physics. Schrödinger also showed that both his and Heisenberg's representations are mathematically equivalent. Today we speak of different concrete representations of an abstract Hilbert space structure. Like every differential equation, the Schrödinger equation also describes a deterministic process. However, this deterministic development only concerns the possibilities. The "randomness" in the context of quantum theory results from the facts that are found in a measurement on the system.

[4] Schrödinger accordingly formulates that a measurement is an interaction between two systems that constitutes a certain *catalog of expectations* , which in turn must contain both certain and undetermined elements due to the limited information content.
"In the catalog, not only new entries, but also deletions must have taken place. Knowledge can be acquired, but not lost. The deletions therefore mean that the previously correct statements have now become false. A true statement can only become false if the object to which it refers changes". The ψ-function of the Schrödinger equation would thus completely describe the state of the quantum system resulting from the experimental set-up: The properties of the system would be characterized by the "expectation catalog", which, as stated, must contain both definite and indefinite elements, since the "maximum sum of knowledge" of the quantum system is limited. For Schrödinger, the quantum state or the wave function are only representations of expectation catalogs of future experimental results. In modern language, one can say that an entangled state expresses well-defined information about joint measurement results on the entangled systems, but the information for the individual systems is completely undefined. This definition leads directly to modern applications of quantum theory, [such as] quantum computers

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